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Evaluation of greenhouse gas reduction strategies for urban passenger transport

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Abstract

Two very different approaches to large-scale greenhouse gas emission reductions from urban passenger transport have been extensively discussed and researched in recent years. The first concentrates on the technical efficiency of travel, and attempts to reduce emissions by using alternative fuels or power systems, modal shift, fuel efficiency improvements to existing vehicle types, or increasing occupancy rates. We show that the popular preferred option, a zero or low emission car with costs, performance and convenience of use similar to existing cars, is unlikely to achieve high fleet penetration for decades, if ever, as too many technical and economic uncertainties remain. Other efficiency approaches, such as improving car occupancy rates or use of much smaller cars, require no technical breakthroughs, but would, for many motorists, destroy the convenience and comforts of private travel.

The second approach attempts to reduce the demand for travel itself, for example by altering land use in cities. We find that feasible residential density increases will be ineffective in reducing travel in Australian cities. The best option appears to be introducing measures aimed at reducing the speed and convenience of urban car travel, which should not only reduce urban travel demand itself, but also encourage a shift to more environmentally benign modes. Voluntary programs, such as Perth's Travel Smart, can not only get this shift underway, but can prepare the ground for less popular, but necessary, measures.

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Introduction

The latest report of the Intergovernmental Panel on Climatic Change (Wigley and Raper 2001) projects that the earth's surface will warm on average by from 1.4 to 5.8 ^{o}C over the 21st century. If the warming is at the upper end, the climatic changes would be very serious indeed. Australian per capita emissions of CO_2, the main trace gas, are several times larger than the global average (World Bank 2001). In 1994/5, the total emissions from energy combusted domestically was 303.0 megatonnes (MT) CO_2-equivalent (Australian Bureau of Statistics (ABS) 2001a). All forms of transport in Australia in the same year released 93.2 MT, or about 31% of the total (Lenzen 1999). This transport figure includes emissions released during fuel conversion as well as vehicle operation. If large emissions reductions are required, it seems evident that transport emissions will not be exempted. Further, urban private travel emissions will likely be stressed ahead of either rural private travel, where alternatives are more limited, or freight transport, which is more important for the economy.

This paper examines the various approaches available for reducing emissions from urban passenger travel. Two general approaches exist. The first attempts to reduce the impact of existing vehicular travel by cutting emissions per kilometre of travel, for example by improving fuel efficiency. The second approach aims at reducing the total vehicle-km travelled, for example by changing land use in cities. Each is discussed in turn in the next two sections. We find that several measures have the potential for deep reductions in emissions, but no easy solutions are available. The best option appears to be introducing measures aimed at reducing the speed and convenience of urban car travel. Although deep reductions will most likely require large changes in urban travel behaviour, voluntary car travel reduction programs can get the process underway.

Reducing emissions per passenger-km

The measures discussed in this section are generally relevant to all transport, urban and rural, passenger and freight. Additionally, any success in reducing greenhouse gas emissions will usually be accompanied by reductions in oil use and local air pollutrion emissions. Their cost effectiveness will not only depend on greenhouse gas reductions.

Using alternative transport fuels and propulsion systems

Proposed alternatives include LPG, various fuels derived from natural gas, biomass-derived alcohols and electricity or hydrogen from renewable sources. Whatever their merits in saving oil or reducing local air pollution, their greenhouse gas benefits may be small or even non-existent. For large emission reductions, alternative fuels must meet the following conditions:

- They must be available for many decades in large annual amounts
- They must not be much more expensive than existing oil-based fuels
- They must not decrease Australian greenhouse gases at the expense of global emissions.

Two frequently discussed alternatives are themselves fossil fuels. Natural gas can be used directly in vehicles as compressed or liquefied natural gas, or after processing, in the form of methanol. But careful analyses in the US of greenhouse gas emissions over the full fuel cycle show no consistent reductions for any natural gas-based vehicle fuel compared with existing oil-based fuels, when all greenhouse gases are taken into account (Wang 1997). A recent proposal sees natural gas used as an auxiliary feedstock for biomass alcohol fuels in the US transport sector (Borgwardt 1999). Greenhouse gas emissions are greatly reduced compared with biomass fuels used alone, but natural gas reserves are finite, and global consumption for conventional purposes is steadily growing. LPG, the only alternative in widespread use in Australia, does produce emission reductions compared with petrol, and is the subject of another paper to this conference (Honnery, Ghojel and Moriarty 2002).

In the US, ethanol made from corn is not only expensive, but very large-scale production would give only modest reductions in greenhouse gas emissions compared with oil-based fuels. Interest there has thus shifted to alcohols produced from cellulosic biomass (Borgwardt 1999). A case can certainly be made for some ethanol production from forest, farm, and municipal wastes, if it can be done economically. But probably only small amounts of liquid fuels can be produced from crop and forest wastes without increasing soil erosion, lowering soil fertility, or, in Australia, reducing woodchip exports. Much attention has therefore been focussed overseas on specially grown energy crops.

If biomass liquid fuels are to replace a significant share of transport oil-based fuels, they will require either vast areas of fertile land, or alternatively, large inputs of fertiliser, water, and transport, if more marginal land was used. The first option could well merely result in the displacement of some food-growing from Australia to less suited areas in under-developed food inporting countries. Australia’s emissions may be reduced, but could be more than offset by increased emissions overseas. Furthermore, Australia presently exports over 50% of its agricultural output (ABS 2002). Any future increases in population and per capita incomes will require continued increases in output for local consumption and exports. Use of marginal land for biomass fuels, with its need for high inputs, on the other hand, may also give few if any benefits in emissions over oil-based fuels. In summary, biomass alcohols, although they can be readily blended with petrol, offer few emission reduction benefits for Australian transport.

Battery electric vehicles can reduce local air pollution, but what of global air pollution? Australian emission levels would rise if electric vehicles replaced existing cars, because of our largely coal-based electricity grid. The need for vehicle heating in winter would further raise emissions, especially if fossil fuel (e.g. propane) heaters were used (Moriarty and Wellington 1996). If the electricity was produced using renewable sources, a real ‘green car’ would be available, with no emissions, local or global, and no petroleum use. At best, such vehicles can only ever capture a small fraction of the urban travel market, because they not only have a lower range than conventional cars, but cost a lot more. After many years of research, it has been difficult to find a battery that has an acceptable combination of satisfactory power and energy density, durability, recharging time, cost, and operating safety, and made of materials that are both non-toxic and in plentiful supply. This lack probably explains why interest has shifted overseas to hybrid vehicles and hydrogen fuel cell vehicles.

Hybrid electric vehicles include Toyota’s Prius and Honda’s Insight. Hybrids have two on-board power supplies (a small internal combustion engine, and an electric motor) together with a small battery pack. Electric drive makes regenerative braking possible, allowing at least some of the kinetic energy usually lost during stop-start urban driving to be transferred to the storage battery. Another advantage is that the petrol engine can be smaller than in the equivalent conventional car, and further can be run near its optimum operating point for energy efficiency. Hybrids are therefore more efficient than similar petrol cars — and more expensive. (Both Toyota and Honda are believed to be subsidising their hybrids.)

Hybrids are still fuelled by petrol or diesel. Hydrogen-powered fuel cell vehicles, still in the development stage but optimistically promised later this decade, could remove this difficulty, and give us a green transport system. This is still many decades away, since not only are the vehicles not yet available, but a hydrogen gas infrastructure is nowhere in existence, nor in Australia a power grid based on renewable electricity. Indeed, the share of renewable electricity in Australia is falling. It was nearly 20% in 1973/4, but today is under 10%, and its share, even with the government’s Mandated Renewable Energy Target, is not expected to increase over the next two decades (Bush, Holmes and Trieu 1995; Dickson, Short, Donaldson and Roberts 2002).

Until a hydrogen infrastructure is built, fuel cell cars will have to use specially formulated petrol, and reform it on board to produce the hydrogen. (Methanol has also been proposed as the transition fuel, but again, no distribution system presently exists.) But as Appleby (1999) stresses, such vehicles would produce little energy use or emissions savings compared with an equivalent hybrid car, because of energy losses to the compressors and reformers. Even high-volume production of fuel cell vehicles might not reduce overall costs, because the increased demand for platinum as a catalyst would raise its price. Platinum availability would also limit the rate at which such vehicles could be introduced worldwide (Borghardt 2001). Fuel cell cars could experience further problems with on-board hydrogen storage, and for this reason fuel cells may be better suited to heavier vehicles (Farrell and Keith 2001).

Improving the fuel efficiency of conventional passenger vehicles

Much potential exists for improved fuel efficiency of internal combustion engine cars, (Hawken, Lovins, and Lovins 1999) but the past record suggests it is difficult to achieve. The periodical ABS motor vehicle usage surveys show that the fuel efficiency of the Australian car fleet has improved very little over the past 30 years, and little change is expected over the next decade (ABS 2001b; Dynamic Transport Management 1997). Any technical gains have been nullified by increased auxiliary power requirements and growing popularity of four wheel drive vehicles.

Two approaches are available for improving vehicle fuel economy. The first is to improve engine efficiency. The second is to reduce the ‘road load’, by cutting the weight of the vehicle, the rolling resistance of the tyres, and the air resistance. The second approach seems best, especially reductions in vehicle weight (Moriarty and Honnery 1999), since we may well move away from internal combustion engine vehicles anyway. Vehicle weight reductions will be beneficial for all fuels and engine types. But reducing vehicle weight will not be easy, if overseas experience is any guide. In the US, about half the new personal transport vehicles sold are now ‘sports utility vehicles’, heavier than automobiles. Europe, during the 1950s and 1960s, sold millions of fuel efficient small cars (Riley 1994), but rising affluence led to their demise. The fuel efficiency of trams and trains can also be improved, as these vehicles presently have high weight per seat provided.

Switching to more efficient transport modes

Different existing modes of transport have different environmental impacts. Public transport is more ‘greenhouse gas efficient’ (as measured by kg of CO_2 equivalent per passenger-km) than car travel, as can be seen in Table 1. The values in the table include emissions during fuel conversion (for example from power stations in the case of electric trains) as well as during vehicle operation. All values are at prevailing occupancy rates. Urban rail transport (nearly all electric) is over twice as efficient as urban car travel. This advantage would be even more pronounced at peak-hour, given that the occupancy rate of cars for work travel (under 1.1) is much lower than the average of 1.5-1.6 persons per car for overall travel. For electric public transport, however, the gains are reduced because emissions of CO_2 per unit of energy are higher for coal than for oil.

Table 1 Greenhouse gas efficiency (Kg CO_2 equiv./pass-km) of Australian urban passenger transport, 1994/5 (Source: Apelbaum Consulting Group 1997)

	Car	Train	Tram	Bus
All urban	0.19	0.09	0.11	0.17
---peak	*NA*	*0.04*	*0.07*	*0.14*
---off-peak	*NA*	*0.16*	*0.13*	*0.21*

Emissions can be lessened by shifting at least some passengers to these more efficient modes. Yet public transport's share of the urban travel market has fallen steadily over the past half century. In Melbourne, for example, it fell from around 80% in 1947 to under 10% today (Moriarty 1996). Urban electric public transport is particularly suited to assume a larger role in future. Even with coal-based electricity, it is already superior to car travel on greenhouse gas emissions. Some electric transport already exists in all large capitals, with very extensive networks in Sydney and Melbourne. These existing systems only need renewable electricity as their power source to qualify as 100% green transport.

Increasing vehicle occupancy rates

Occupancy rates for private travel in Australia are still falling. In the 1960s passenger vehicles on average carried over two occupants, but by the early 2000s vehicle occupancy had fallen to 1.5-1.6 persons. Occupancy is highest for weeekend travel, but for the journey to work, the figure is now less than 1.1 per vehicle (ABS, 1996). Similar declines have been found in North America and Europe. Clearly, great potential exists for higher loadings in cars, but with falling household size and ever-rising car ownership, it will be very difficult to achieve. Programs to encourage car pooling in the US and elsewhere have met with little success. Motorists seem resistant to sharing their vehicle with non-family members—understandably, since people have different tastes in music or radio station, in their degree of driving caution, and in standards of punctuality. All these differences dampen enthusiasm for car-pooling, at least when car ownership is high and perceived car travel costs low. Car pooling can also sometimes interfere with attempts to combine trips, an important alternative means of reducing car travel.

The situation is very different for public transport occupancy rates. Here, vehicle occupancy rates should rise as overall patronage rises. Conversely, they fall as overall patronage declines, as has happened historically. Melbourne's suburban rail system, for example, carried 154 million passengers overall at an average of 29 passengers per carriage in 1960. By 1980, patronage had fallen to 86 million, and passengers per carriage to 19 (Newman and Kenworthy 1989). Policy initiatives which boost public transport will usually also increase vehicle occupancy rates, mainly because much of the increase in patronage will be accommodated on existing services. New services will usually only be introduced when existing services are judged as too crowded. In contrast, the growth in car travel has, as shown, been accompanied by declining occupancy rates.

Reducing the demand for travel by land use changes

Recently, much interest has been shown in the possibility of modifying urban form to reduce car travel and encourage other modes (Handy 1996; Newman and Kenworthy 1999; Moriarty 2002). Newman and Kenworthy, in their survey of 46 world cities, including six from Australia, have shown that, per capita, total vehicular travel and travel energy both decrease as urban population density increases. But it is difficult to make meaningful comparisons between cities in countries with very different income levels and motoring costs, let alone different ways of defining urban boundaries. Accordingly, here we only compare Newman and Kenworthy's six Australian capital cities, as the relevant urban density and travel data are collected in a similar way for all capitals, and income levels, particularly for the five large state capitals, are similar.

Transport, income, and urban density data are shown in Table 2. All data except for urban density refer to Statistical Division boundaries. Although density varies by a factor of two, vehicular passenger-km per capita is as large in the higher density as in the lower density cities. Indeed, low density Canberra has the lowest travel levels when adjusted for income (see last row in Table 2). True, the urban density range is not nearly as large as in the global comparison, but it covers the range of politically feasible density increases for the smaller, lower density, Australian capitals. Given continued decline in family and household sizes, it is very hard to see Perth or Brisbane ever doubling their urban densities. It is at least possible, though, that densities very much higher than Sydney's could reduce travel, as discussed below. It is also possible that travel is reduced in the higher density Australian cities, but that any reductions are offset by their larger size. City size is an important factor for some trip lengths. Trips made to the city centre, for example, are longer on average in Sydney and Melbourne simply because the average resident lives further from the CBD than is the case for smaller cities (Moriarty 1996). Nevertheless, public transport use per capita is much greater in Sydney than elsewhere (Newman and Kenworthy 1999), suggesting that density is an important factor in patronage.

Higher population densities can potentially influence travel levels and mode choice in several ways. First, for a given income level, a given area can support a higher density of shops and services of all kinds. Therefore, the distance to the nearest shopping centre should be lower in denser cities. The problem is that residents today don't necessarily use their nearest shopping centre. A recent shopping survey in Canberra illustrates this point well (ABS 1998). Canberra, unlike the other five capitals, has a defined hierarchy of shopping centres: Local, Group, and Town centres. In the survey, a Local centre was the nearest shopping centre for 69% of the population, a Group centre for 27%, and for a Town centre, only 4%. Yet only 19% of households overall usually did their major food and grocery shopping at their nearest centre. For the majority living nearest to a Local centre, nearly all of which have supermarkets, the figure fell to 5%. (Nearest centres were, however, more popular for convenience items). These findings can probably be extended to services of all kinds in our cities, given the present convenience and perceived cheapness of car travel.

Table 2 **Transport and land use data, *circa* 2000 (Sources: Apelbaum Consulting Group 1997; ABS 1996, 2000, 2001b, 2002; Newman and Kenworthy 1999)**

	Syd.	**Melb.**	**Bris.**	**Perth**	**Adel.**	**ACT**
Pop. (m.) (2000)	4.086	3.466	1.627	1.381	1.096	0.311
Urban density (1996)	2030	1600	1020	1200	1350	1290
Veh. pass.-km per cap. (2000)	12 650	13 250	13 360	11 860	11 060	11 360
Income per capita ($/yr) (1998/9)	19 712	19 499	17 102	18 682	17 531	23 141
Veh. pass-km/$ income (1998-2000)	0.642	0.680	0.781	0.635	0.631	0.491

The second way in which higher densities can lower travel, and with it greenhouse gas emissions, is by increasing both traffic congestion and parking difficulty. The result is much lower door-to-door speeds for private travel, which can erode its door-to-door speed advantage over alternative modes. Congestion and the resulting lower convenience of car travel undoubtedly partly explain the much lower levels of private travel in densely populated Hong Kong and Tokyo, cities with per capita incomes similar to Australian cities.

Fortunately, massive density increases, even if politically feasible, are not the only way of achieving such travel reductions. It is theoretically possible to mimic the effects of high urban densities (and alter private travel convenience) by policy changes, such as much lower urban speed limits, parking restrictions, priority for street public transport, an end to urban arterial road building, traffic-free precincts, and even road closures. Such measures could be implemented much faster than the decades likely required for major density increases. They would, of course, be unpopular, but probably less so than trying to increase the density of our cities to the levels in east Asia. All these measures have been implemented to some extent in certain European cities (Newman and Kenworthy 1999). In Graz, Austria, most of the city now has a 30 kph speed limit, which is now supported by eight out of ten people (Pilkington 2000).

Policies for emissions reduction

The ideal way of cutting emissions would be to use an abundant fuel which costs about the same as petrol, and could be used in existing vehicles. It is not hard to see why such a solution has been eagerly sought. Unfortunately, as argued above, such a painless solution does not exist. The next best solution would require both a new fuel and new vehicles, but again with costs and convenience of use similar to existing cars. Hydrogen fuel cell vehicles have been proposed for this role, but may never match present petrol cars on cost. Even if they do, it will require decades for introduction of a hydrogen infrastructure based on renewable energy. This approach is also risky: if fuel cell vehicles don't work out, we will have very little to show for the investment. Fuel efficiency improvements are of course welcome, but can only bring about minor reductions, for several reasons. First, vehicle numbers and total vehicle-km are still rising in Australia. Second, the inevitable increased reliance on unconventional sources of oil (such as shale oil and tar sands) means that the greenhouse emissions per litre of fuel delivered will steadily rise in future. Third, projected growth of in-vehicle electronics will increase power demands. Overall emission reductions from efficiency improvements are therefore likely to be small.

The remaining options detailed above are more promising, in that they face no technical obstacles, and can in principle be implemented without increasing the monetary costs of travel. Indeed, they will usually lower unit travel costs. For example, a smaller car is cheaper to run than a large car. But the continuing decline in popularity of car pooling, alternative modes, and smaller cars, as documented above, shows that lower costs in themselves are not a sufficient attraction if average real incomes continue to rise.

Major long-term real cost increases for motoring are probably inevitable given likely future price rises for oil (Anon 2001), but even these may not significantly reduce car use and thus emissions. In the U.K. and Norway, both major oil producers, petrol costs are more than twice as high as in Australia. Yet their passenger vehicle-km per capita are not much below Australia's (International Roads Federation 2002). Petrol cost rises will need to be very high to deliver large emission reductions. Since most lower-income households own cars, they would be disproportionately affected by very steep cost rises. Further, households with lower per capita incomes are increasingly found in the outer suburbs of our large cities. Here, not only are travel needs higher, but alternatives to the car are less available than in the middle and inner suburbs (Moriarty 2000). At present they would be doubly disadvantaged by high vehicle operating costs.

How can reductions in travel greenhouse gas emissions be best brought about? The best options, in our view, lie in a combination of reductions in travel itself and a switch to alternative modes. Much of the huge growth in post-war urban personal travel has been created by the car. Suburbanisation of workplaces, as well as shopping and other service industries, now makes travel reductions feasible, even if it has also made car travel more convenient (Moriarty 1996). What are needed are policies already discussed, such as speed limit reductions, which will decrease car travel convenience and encourage shorter, more local trips. As the Canberra example shows, merely providing local shops is not enough if car travel convenience remains high. These travel restraint policies are also more equitable than relying largely on motoring cost increases. And unlike major density increases, or other land-use changes, they can be rapidly implemented, given the necessary political support.

The existing alternative modes have a core market which they dominate, other trip types for which they are at least presently ill-suited, and yet others where even today they can potentially compete with presently-favoured modes. The measures needed for travel reduction also support a shift to alternative modes, since they expand the range of trips where the other modes can successfully compete with the car. Thus non-motorised trip-making could be greatly expanded at the expense of short car trips. Similarly, public transport could be used for nearly all trips to, from, and within the inner area of our large cities. The occupancy rate for public transport should also increase. For equity reasons, public transport services in the outer suburbs would need to be enhanced in both coverage and frequency. Lowering urban speed limits would also improve the operating fuel efficiencies, by reducing vehicle road load (Moriarty and Honnnery 1999).

The recognition that for some trips at least, there are alternatives to car travel, lies at the heart of an innovative program in Perth by the WA Department of Transport. Travel Smart was developed as an important means of achieving the Metropolitan Transport Strategy’s target of achieving a reduction in car-as-driver trips of around 35% by the year 2029. Travel Smart aims to make Perth residents less reliant on the car by converting some of the trips presently made by car drivers (but for which alternatives exist) to other modes. Travel Smart was trialled in South Perth, and achieved a reduction in car-as-driver trips of 14% (Anon 2000). Surveys suggest that the approach should enjoy similar success in middle and even outer areas of the city (Socialdata 2000). The approach shows promise in changing people’s attitudes toward more environmentally benign travel alternatives. Not only does it offer immediate (and cost-effective) greenhouse gas reductions, but it should also prepare the ground for the other car travel reduction policies discussed above.

Conclusions

The most popular means of reducing emissions would be to use a new fuel (and possibly, new vehicle types as well) with costs and convenience similar to existing car operation, as these require least social changes. This option does not exist today in Australia, and may not for decades, if ever. Other approaches, such as improving car occupancy rates or use of much smaller cars, require no technical breakthroughs, but would, for many motorists, destroy the convenience and comforts of private travel. They should be encouraged, but cannot be expected to lower emissions much, even if car travel costs rise.

Increasing residential densities does not seem to lower per capita travel in Australian cities, although it can promote use of alternative modes. The option favoured here is the introduction of measures aimed at reducing the speed and convenience of urban car travel. These could include speed limit reductions, parking restrictions, and traffic free precincts. These measures should not only reduce urban travel demand itself, but should also encourage a shift to alternative modes, because car travel would no longer enjoy a door-to-door speed advantage over the alternatives for many trips. No solution that will be effective is likely to be popular, but city-wide traffic restraint and encouragement of alternatives are more equitable measures than relying solely on cost increases. Although deep reductions will most likely require large changes in urban travel behaviour, voluntary car travel reduction programs, such as Perth's Travel Smart, can get the process underway.

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